

## RING GEAR AND MANUFACTURING METHOD FOR SUCH A RING GEAR

### FIELD OF THE INVENTION

**[0001]** The present invention relates to a method of manufacturing a ring gear and more particularly to a method of manufacturing a ring gear from a billet.

### BACKGROUND OF THE INVENTION

**[0002]** Traditionally, automotive ring gears have been manufactured by press forging solid blanks at temperatures approaching 2200°F. Immediately after the pressing operation the “as forged” ring gear blanks enjoy significantly improved mechanical properties over that of the solid blanks. However, because of the exacting tolerances generally required of such ring gears, the as forged ring gear blanks must be machined to their final, or net, shape. The forging process, though, hardens the material to such an extent that machining the ring gear is economically impractical. Accordingly, the ring gears are typically annealed after forging and then machined. Thus, the traditional method of manufacturing ring gears cannot take full advantage of the superior “as forged” properties. Moreover, because annealing requires the application of heat to the ring gear for a period of time, annealing consumes energy. Additionally, the annealing and machining processes consume time and other manufacturing resources.

**[0003]** Additionally, because ring gears often rotate about a shaft (as opposed to being rigidly attached to a differential casing for example) the finished ring gear requires a central aperture through which the shaft fits. Thus, provisions must be made during the manufacture of the ring gear for the central aperture. For instance, a separate mandrel, or punch, may be employed to create the aperture through the solid blank or the ring gear. However, the separate actions required to form the aperture give rise to an offset between the center of the aperture and the center of the pitch diameter of the ring gear. If placed in service in this condition, the ring gear would tend to vibrate as it rotates, causing deleterious wear e.g., on the teeth of the ring gear, the shaft, the shaft bearings, and the overall machine. Consequently, it is frequently necessary to machine the aperture to eliminate or minimize the offset between the center of the aperture and the center of the pitch diameter of the ring gear.

#### SUMMARY OF THE INVENTION

**[0004]** The present invention provides a method of manufacturing a forged article including a surface. The method includes defining a negative tooling pattern based on the surface and providing a tooling set having an anvil and a top and bottom die. An upper surface of the bottom die conforms to the negative tooling pattern. When the tooling is assembled the anvil extends through the bottom die and defines an axis. Additionally, the bottom and top dies cooperate to define a die cavity. A hollow blank is placed on an anvil and into the die. In a single stroke, the hollow blank is pressed between the top and bottom

dies in a pressing direction that is parallel to the axis. During the pressing, the blank initially flows in the pressing direction to form the surface of the article. Thereafter, the blank flows in a direction perpendicular to the pressing direction to fill the die cavity.

**[0005]** In another embodiment, the present invention provides a method of manufacturing a ring gear including a surface having teeth. The method includes defining a negative tooling pattern based on the surface and providing a tooling set having an anvil and a top and bottom die. An upper surface of the bottom die conforms to the negative tooling pattern. When the tooling is assembled the anvil extends through the bottom die and defines an axis. Additionally, the bottom and top dies cooperate to define a die cavity. A hollow blank is placed on an anvil and into the die. In a single stroke, the hollow blank is pressed between the top and bottom dies in a pressing direction that is parallel to the axis. During the pressing, the blank initially flows in the pressing direction to form the surface of the ring gear. Thereafter, the blank flows in a direction perpendicular to the pressing direction to fill the die cavity.

**[0006]** Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]** The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

**[0008]** Figure 1 is a perspective view of an exemplary ring gear constructed in accordance with the teachings of the present invention;

**[0009]** Figure 1A is a cross sectional view of the exemplary ring gear of Figure 1;

**[0010]** Figure 2 is a cross sectional view of an exemplary tooling set for fabricating the ring gear of Figure 1, the tooling set being constructed in accordance with the teachings of the present invention;

**[0011]** Figure 3 is partial cross sectional view of an anvil of the tooling set of Figure 2;

**[0012]** Figure 4 is partial cross sectional view of a sleeve of the tooling set of Figure 2;

**[0013]** Figure 5 is partial cross sectional view of a bottom die of the tooling set of Figure 2;

**[0014]** Figure 6 is partial cross sectional view of a top die of the tooling set of Figure 2;

**[0015]** Figure 7 is perspective view of an exemplary tubular billet and ring shaped blank for use in fabricating the ring gear of Figure 1;

**[0016]** Figure 8 is a cross sectional view of the tooling set of Figure 2 illustrating the ring gear of Figure 1 as formed in the tooling set;

**[0017]** Figure 9 is a plot illustrating press load as a function of the stroke of the press for a ring gear formed in conformance with the methodology of the present invention; and

**[0018]** Figure 10 is an elevation view of a press for use with the tooling set of Figure 2.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0019]** The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. While the invention is herein described with reference to an exemplary ring gear, the invention should not be construed to be so limited.

**[0020]** With reference to Figures 1 and 1A, an exemplary ring gear that has been formed in accordance with the principles of the present invention is generally indicated by reference numeral 10. The ring gear 10 includes a generally ring shaped body 12 that defines a central aperture 14 with an inner wall 15, an outer (or circumferential) surface 16, and a plurality of teeth 18 that cooperate to define a pitch diameter  $d_1$ . Each of the teeth 18 includes a top land 20, and a root 22. Also, for purposes of the discussion herein, the ring gear 10 can be said to have a toothed surface 24, whereon the teeth 18 are located, and an opposite surface 26 that is opposite the toothed surface 24.

**[0021]** In Figure 2, an exemplary tooling set 28 constructed in accordance with the teachings of the present invention and suitable for manufacturing the ring gear 10 is shown. The tooling set 28 may include an anvil

30, a sleeve 32, a bottom die 34, and a top die 36. The material for any of the components of the tooling set 28 may be selected based upon various criteria, including resistance to elevated temperatures, hardness, and wear resistance, for example. In the particular example provided, each of the components of the tool set 28 is formed of CPM® 1V® alloy, which is commercially available from Crucible Compaction Metals of Oakdale, PA. Also shown is a hollow or ring shaped, blank 38 that is formed of a material that has been selected for the end application (e.g. the service expected for the forged article). Other considerations for choosing the material of the blank 38 include formability and post forming treatment requirements such as carborization or induction hardening to meet specific case depth and hardness values .

**[0022]** Briefly, to form the ring gear 10, the sleeve 32 is placed over the anvil 30 with the bottom die 34 being centered over the sleeve 32 and the anvil 30. The ring shaped blank 38 is then centered over the anvil 30 so that it rests on an upper surface 40 of the bottom die 34. The top die 36 is then centered over the anvil 30 so that it rests on a top 42 of the ring shaped blank 38 as illustrated. Next, force is applied to the top die 36 to force it down against the ring shaped blank 38. As the force applied increases, the material of the ring shaped blank 38 yields initially flowing down to fill the voids between the blank 38 and the upper surface 40 of the bottom die 34. Thereafter, the material flows radially outward, or laterally, to fill the void between the blank 38 and the top die 36. When the material of the blank 38 has filled the voids between the blank 38

and the top die 36, the force is removed and the ring shaped gear 10 has been formed.

**[0023]** In Figure 3, the anvil 30 may include a section 44 at one end and a piloting section 46 at the other end. The section 44 may be formed so as to have a constant diameter along its length. The piloting section may be tapered, for example by about 3 degrees, to ease the ejection of the forged article from the tool set 28. As those of ordinary skill in the art will appreciate from this disclosure, the outer diameter of the anvil 30 and sleeve 32 (depending on the axial location) will form the inner diameter of the forged article. Thus, the material of the article and that of the anvil and sleeve may be chosen to minimize, or eliminate, differences in the thermal coefficients of expansion to thereby minimize thermal effects at the point of contact between the anvil and the forged article.

**[0024]** In Figure 4, the sleeve 32 may include a section 48 and a piloting section 50. The section 48 may be employed to align the anvil 30 and sleeve 32 while the piloting section 48 may be employed to form a chamfer on the inner diameter of the forged article. While a taper 48 has been illustrated for forming a chamfer, those of ordinary skill in the art will appreciate that other geometries may be employed. For example, a ridge could be employed to form a counter-bore in the ring gear or the geometric feature (e.g., the taper 48) may be omitted altogether.

**[0025]** In Figure 5, the bottom die 34 may include an upper surface 40 that is defined by a negative tooling pattern 52. The negative tooling pattern 52

reflects the desired shape of the toothed surface 24 (Fig. 1) including apexes 54 and troughs 56 which correspond to the roots 22, top lands 20, and other features of the teeth 18 (Figures 1 and 1A), respectively. It will be understood by those skilled in the art that the finished shape of the toothed surface 24 and the negative tooling pattern 52 may differ to a certain extent. The deviation of the negative tooling pattern 52 from the shape of the toothed surface 24, if employed, may counteract, or offset, various phenomena (e.g., thermal expansion and contraction, shrink, spring back of the blank material, and the like) that are characteristic of the material from which the ring gear 10 is formed. Otherwise, the negative tooling pattern 52 generally reflects the shape of the toothed surface 24 including the gear teeth 18.

**[0026]** The bottom die 34 may also include a body 58 that defines a central aperture 60. In the example provided, the central aperture 60 facilitates the centering of the bottom die 34 relative to the sleeve 32. During the pressing operation, the body 58 serves to support the negative tooling pattern 52 rigidly against the blank 38.

**[0027]** In Figure 6, the top die 36 may include a first body portion 64, which may define a pressing surface 70, a second body portion 66, which extends downwardly from the first body portion 64, and a central aperture 72. The second body portion 66 may include a transition portion 68 that intersects the inner surface 74 of the second body portion 66 and the pressing surface 70. In the particular example provided, the transition portion 68 is arcuately shaped, but those of ordinary skill in the art will appreciate that other geometrical shapes

may be employed in the alternative. Depending on the configuration of the article that is to be forged, the inner surface 74 may be configured such that it slopes radially outward slightly as it descends downwardly to the end of the top die 36 opposite the first body portion 64. While a taper has been shown, other articles may be forged for which the inner surface descends essentially vertically. Again, the features of the tool set 28 depend on the requirements of the article to be forged. The surface 74 may blend into the transition portion 68 that, in turn, may merge into the pressing surface 70. Together the surface 74, the transition portion 68, the pressing surface 70, and the negative tooling pattern 52 define a die cavity 76. The first body portion 64 also defines a central aperture 72 for centering the top die 36 over the anvil 30.

**[0028]** As shown in Figure 7, a hollow, or tubular, billet 78 may be sectioned to create one or more of the ring shaped blanks 38. It should be noted that the tubular billet 78 is generally cylindrical with a central aperture 80 that corresponds to a central aperture 82 in the ring shaped blank 38. The billet 78 may have an inner diameter that fits over the outer diameter of the anvil 30 and an outer diameter that fits into the die cavity. Alternatively, the inner diameter and/or outer diameter of the billet 78 (or the blank 38) may be machined to a desired size.

**[0029]** After being sectioned from the tubular billet 78, the ring shaped blank 38 has a first end surface 84, a second end surface 86, and a circumferential surface 87. Additionally, the ring shaped billet defines a central axis 88 in the direction between the end surfaces 84, 86. In the example

provided, the central axis 88 is generally perpendicular to the end surfaces 84, 86 and coincident to the axis of the central aperture 82. Those skilled in the art will appreciate from this disclosure, however, that the central axis 88 is a reference axis and may be oriented differently with respect to one or more of the end surfaces 82, 84 and the central aperture 82 as desired. Additionally, an inner wall 83 of the blank 38 defines the central aperture 82.

**[0030]** If desired, the blank 38 may be treated in a secondary operation to alter the characteristics of the blank 38 prior to forging and/or to improve the characteristics of the forged article. For example, the blank 38 may be annealed or processed through a shot blasting operation to reduce or eliminate residual stress and/or provide the surfaces of the blank 38 with a desired surface finish. A coating 89 may also be applied to one or more of the surfaces 82, 84, and/or 87 of the ring shaped blank 38. The coating 89 may be a lubricant suitable for use at forging temperatures, such as a graphite-based lubricant, to provide lubricity between the surfaces of the blank 38 and corresponding surfaces of the tool set 28 during the pressing operation.

**[0031]** Returning to Figure 2, the tooling set 28 is shown in an operative manner in conjunction with the blank 38. As illustrated, the section 44 of the anvil 30 extends through the sleeve 32 and the bottom die 34, thereby aligning the centers of these components of the tool set 28. Moreover, the piloting section 46 of the anvil 30 extends from the bottom die 34 to engage the inner diameter of the blank 38 and the top die 36. Thus, the anvil 30 may also align the blank 38 and the top die 36.

**[0032]** Figure 2 also illustrates the blank 38 as it is situated in the die cavity 76 that is formed by the bottom and top dies 34 and 36. In particular, the inner diameter of the blank 38 engages the outer diameter of the anvil 30. The circumferential surface 87 (Figure 7) of the blank is spaced apart from the inner surface 74 of the top die 36. During the pressing operation (as discussed herein), the blank 38 will flow laterally at one point in the forming operation to fill the void between the circumferential surface 87 and the inner surface 74. Moreover, the blank 38 is shown centered over the bottom die 34 and resting on the apexes 54 of the negative tooling pattern 52. Accordingly, when the ring gear 10 is formed, the features of the ring gear 10 will be accurately located with respect to a central axis 90 of the ring gear that generally corresponds with the central axis 88 of the ring shaped blank. Thus, the ring gear 10 will be formed in a concentric manner.

**[0033]** Moreover, the ring shaped blank 38 is shown, in Figure 2, to be positioned on the bottom die 34 such that one of its end surfaces, for example, end surface 86 is proximate the negative tooling pattern 52. Thus, when the blank 38 is pressed, the end surface that is proximate the negative tooling pattern 52 (i.e., end surface 86 in the example provided) will form the front 24 of the ring gear 10. Those skilled in the art will appreciate from this disclosure that in some situations, it may not be necessary to orient the blank 38 in the die cavity 76 in any particular manner and as such, the blank 38 may be flipped so that either of the end surfaces 84, 86 may be positioned proximate the negative tooling pattern 52.

**[0034]** In some circumstances, for example where the end surfaces 84, 86 are not generally parallel one another, there may be a need to orient the blank 38 into the die cavity 76 in a predetermined manner. Similarly, the other end surface of the ring shaped blank 38 (i.e., end surface 84 in the example provided) will form the back 26 of the ring gear 10. Also, a plurality of teeth voids 92 may be seen defined between the negative tooling pattern 52 and the bottom 86 of the ring shaped blank 38. Similarly, an annular void 94 may be seen defined between the circumferential surface 87 of the ring shaped blank 38 and the inner surface 74 (with the arc 68, the pressing surface 70, and the bottom die 34 completing the definition of the annular void 94).

**[0035]** In operation, the tubular billet 78 is sectioned to form the ring shaped blank 38. In the particular example provided, a 1.5-inch section of a 5.0 inch inner diameter by 8.0 inch outer diameter steel tube forms the ring shaped blank 38. It should be noted that the die cavity 76 of the top die 36 is designed so that when the ring shape blank 38 has been pressed to the desired thickness the resulting ring gear just fills the die cavity 76 around the anvil 30 (except, of course, for the portion of the die cavity 76 accounted for by the stroke of the top die). In the particular example provided the die cavity 76 is designed to accommodate a 11 pound ring gear 10 made from an 18 pound solid billet.

**[0036]** After sectioning, the blank 38 in this example was shot blasted and a coating 89 was applied to the ring shaped blank 38 to reduce friction between the blank and the tool set 28 during the pressing operation.

**[0037]** With reference now to Figure 10, a press 120 is prepared for pressing the blank 38. The press 120 including a platen 122, a ram 124, a hydraulic system 126, and an induction heater 128 for use with the exemplary tooling set 28. The bottom die 34 may be placed over the anvil 30 and bolted to (or otherwise rigidly attached to) the platen 122. The ring shaped blank 38 may be positioned over the anvil 30 and brought down against the bottom die 34. The top die 36 may be positioned over and in close proximity to the blank 38.

**[0038]** The induction heater 128 may be employed to heat the blank 38 to a predetermined temperature prior to the forming of the blank 38. In the example provided, the predetermined temperature may be about 1700 degrees Fahrenheit to about 1800 degrees Fahrenheit. In addition, the anvil 30, sleeve 32, and the dies 34 and 36 may be heated in press 120 by a gas fire to about 300 ° F.

**[0039]** The pressing stroke is initiated wherein the ram 124 moves toward the platen 122 so that the top die 36 is translated toward the bottom die 34 via hydraulic pressure that is supplied by the hydraulic system 126. The pressure on the blank 38 builds rapidly beyond the yield point of the blank 38 causing the material that forms the blank to flow in an axial direction generally parallel to the pressing stroke into the teeth voids 92.

**[0040]** When the bottom of the blank 38 conforms to the top of the negative tooling pattern 52 that was originally directly under the blank 38, the axial flow of the material that forms the blank 38 stops and flows instead in a radial direction that is generally perpendicular to the pressing stroke. Any voids

that may have existed between the anvil 30 and the blank 38 (e.g., due to run out or differences in concentricity), the material that forms the blank 38 flows laterally inward to fill the void. The material that forms the blank 38 will also flow radially outward, thereby filling the annular void 94.

**[0041]** The pressing stroke is halted when the radial flow (that follows the axial flow) has been halted. If the blank 38 included excess material, it will appear on the back 26 of the ring gear 10. Thus to minimize excess material on the ring gear 10, the blank 38 may be volumetrically controlled (i.e., one or more of the height, outer diameter and inner diameter may be machined as necessary to put the blanks 38 in a condition wherein they are of a predetermined volume) or the blank 38 may be controlled by weight (i.e., one or more of the height, outer diameter and inner diameter may be machined as necessary to put the blanks 38 in a condition wherein they are of a predetermined weight).

**[0042]** Figure 8 illustrates the net formed ring gear 10 still in the dies 34 and 36 while Figure 9 illustrates the force applied during a typical stroke. It should be noted that during the flows, the material of the blank 38 may be dynamically re-crystallized. In the particular example provided, the grain size of the material from which the gear 10 is made has a re-crystallized grain size of about 7 to about 8 ASTM grain size.

**[0043]** When the ram 124 returns the top die 36 to a condition that is elevated above the lower die 34, the anvil 30 ejects the net formed ring gear 10 from the bottom die 34. Importantly, the ring gear 10 is concentric and the teeth 18 have been net formed (as shown in Figure 8). Thus, the as forged ring gear

10 requires little, if any final machining. Moreover, any excess material of the blank 38 will be found at the back 26 of the ring gear 10 where it may be easily removed. Accordingly, the prior art of annealing and machining steps may be reduced, or eliminated with significant cost savings accrued accordingly.

**[0044]** While the invention has been described in the specification and illustrated in the drawings with reference to various embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention as defined in the claims. Furthermore, the mixing and matching of features, elements and/or functions between various embodiments is expressly contemplated herein so that one of ordinary skill in the art would appreciate from this disclosure that features, elements and/or functions of one embodiment may be incorporated into another embodiment as appropriate, unless described otherwise, above. Moreover, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment illustrated by the drawings and described in the specification as the best mode presently contemplated for carrying out this invention, but that the invention will include any embodiments falling within the foregoing description and the appended claims.